Y-1935

AN ULTRASONIC-ACOUSTIC GRINDER
SETTING STATION

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OAK RIDGE Y-12 PLANT
OAK RIDGE, TENNESSEE

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26

ABSTRACT

A grinder setting station was designed to use a replaceable tool ball coupled to an ultrasonic acoustic-emission detector. A precision of $\pm 40 \mu\text{in}$ ($\pm 1.0 \mu\text{m}$) was realized in the laboratory. The station was designed for automatic wheel setting on a numerical-controlled machine. Included in the report are considerations and laboratory and field test results.

CONTENTS

SUMMARY	4
INTRODUCTION	5
AN ULTRASONIC-ACOUSTIC GRINDER SETTING STATION	6
Facility Design	6
Sensing Method	6
Detector and Post Design	6
Electronic Design	8
Test Results	9
Laboratory Tests	9
Field Tests	9
Numerical-Control Machine Tests	9
Specifications	10
Sensing Method	10
Detector	10
Repeatability	10
Outputs	10
Controls	10
Time Constant	10
Power	11
Physical	11
Application Precautions	11
REFERENCES	12
ACKNOWLEDGEMENTS	13

SUMMARY AND SETTING STATION

An ultrasonic-acoustic grinder setting station has been developed to aid in correcting a common source of dimensional errors in precision grinding. A tool ball is acoustically coupled to a piezoelectric crystal for detecting the contact between the ball and grinding wheel. This system exploits the poor ultrasonic coupling of some fibrous materials (phenolics) to isolate the detector from external shock and vibration, and electronics tuned to operate at ultrasonic frequencies to enable its use for automatic setting on numerical-controlled (NC) grinders. A laboratory precision of $\pm 40 \mu\text{in}$ ($\pm 1.0 \mu\text{m}$) was realized. Field use with automatic setting of an NC grinder was successful. The observed deviation was considerably worse than in the laboratory, but was attributed to machine or mount instability.

The setting station at YAF was developed by using a piezoelectric crystal to detect the contact between the tool ball and grinding wheel. The system was designed to operate at ultrasonic frequencies to enable its use for automatic setting on numerical-controlled (NC) grinders. A laboratory precision of $\pm 40 \mu\text{in}$ ($\pm 1.0 \mu\text{m}$) was realized. Field use with automatic setting of an NC grinder was successful. The observed deviation was considerably worse than in the laboratory, but was attributed to machine or mount instability.

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INTRODUCTION

Contour grinding is a preferred method for fabricating high-precision parts, especially when hard materials are used or a fine surface finish is desired. However, dimensional errors can occur when using this method because of errors in positioning the grinding wheel. Errors and changes in grinding surface position may be due to wheel wear, spindle growth, temperature changes, wheel-size changes due to truing, or machine instability. On a good, stable grinder, operated in a temperature-controlled environment, these errors can be minimized by an accurate method of determining the relative position of the actual grinding surface on the grinding wheel and adjusting the machine program to compensate for true wheel position. This operation is usually called "wheel setting".

Wheel setting, in general industrial practice,^(1, 2) is done manually by a skilled machine operator. The operator detects the point where a cautiously positioned grinding wheel just contacts a previously inspected part (or a precisely located wheel-setting station) on the machine. Contact is sensed by listening for the high-pitched noise that accompanies material removal by the grinding wheel or by observing visible sparks when a dry wheel is used. The machine controls are then adjusted to compensate for any indicated position error and a forming cycle initiated. The setting operation may have to be repeated several times during fabrication of a single part, due to wheel wear or truing. These techniques are largely dependent upon operator skill and experience; therefore, the accuracy is highly variable.

The preferred form of sensor is a tool-setting station, positioned on the machine such that both machine slide axes can be automatically set from the one station. To allow for nicks and wear, the grinding-wheel contacting element should be a replaceable tool ball. The station must be rugged, stable, and impervious to grinding wheel coolant. Setting operations, however, can be done with coolant flow off.

With these requirements in mind, an automatic grinder setting station was developed at the Oak Ridge Y-12 Plant^(a) for use with NC grinders. A visual readout is also provided with the station so that it can also be used to set manual or template grinders.

(a) Operated by the Union Carbide Corporation's Nuclear Division for the US Atomic Energy Commission.

AN ULTRASONIC-ACOUSTIC GRINDER SETTING STATION

FACILITY DESIGN

Sensing Method

For high-finish grinding, the wheel may contact the work at only one or two high spots as it rotates. Rubbing of these high spots against the work surface removes very small amounts of material in a fashion similar to extremely fine single-point machining. For accurate location of the grinding surface position, these high spots must be sensed as the wheel rotates. This requirement precludes the use of normal static inspection tools (eg, dial indicators and LVDTs). In addition, the poor electrical conduction of grinding wheels eliminates eddy-current, capacitance, and spark-gap noncontact gaging schemes.

Three sensing methods have already been examined at Y-12: (1) electrically sensing the open circuit when a small wire is ground in two, (2) using a commercial noncontact air gage, and (3) using a sonic sensor that includes a phonograph cartridge and oscilloscope to monitor the "noise" produced by light contact between a rotating grinding wheel and a precision tool ball. The third method was the most accurate in the preliminary investigation, but was sensitive to external shock and vibration which would interfere with its accuracy in an automatic system due to the many false acoustic signals.

In order to decrease the sensitivity to external noise sources, the phonograph cartridge was replaced by an acoustic emission detector that is sensitive in the ultrasonic frequency region only. By operating in this frequency region, a stable mounting system with high ultrasonic losses can be used to reduce the coupling for external shock and vibration and isolate the detector from the machine base and surrounding activity.

Detector and Post Design

The acoustic-emission detector uses a PZT-5 ceramic crystal which is split in half and connected differentially in series. This arrangement permits use with a differential preamplifier for an improved common mode and interference rejection. The detector is mounted inside a brass case and potted in place with epoxy, as indicated in Figure 1. The brass case is threaded so that it can screw onto the ball support post, and electrical connections are made through a Type TNC (Twin-Ax) connector. The epoxy acts as an ultrasonic coupler as well as a potting agent. This material provides a rugged sealed unit which is impervious to the grinder coolant fluids.

When in use on a machine, the detector is screwed onto the bottom of the ball support post and a precision tool ball placed on top of the post (see Figure 2). The post, made of brass, stainless steel, or some other good ultrasonic-transmission material which is dimensionally stable, consists of a straight rod with an inverted 120° cone in one end and 3/4-12 thread on the other. When the post is first fabricated (or when worn), a tool ball should be seated by lapping it into the cone to ensure a stable support and good coupling between the ball and support post. A small dab of silicone stopcock grease is used to improve the ultrasonic coupling between the ball and ball-support post, and between the post bottom surface and the detector-epoxy potting.

Figure 1. ACOUSTIC EMISSION DETECTOR ASSEMBLY OF THE GRINDER SETTING STATION.

Figure 2. BALL POST ASSEMBLY OF THE GRINDER SETTING STATION.

The phenolic yoke, that holds the ball-support assembly on the machine, attenuates ultrasonic signals which would otherwise couple from the machine frame to the detector, and helps isolate the assembly from external interference. A fibrous material with good dimensional stability but high ultrasonic attenuation is needed for the yoke so that it can both isolate the detector and keep the ball position stable. Care must be taken during assembly or adjustment to prevent contact between the detector case and the machine mount in order to preserve the yoke ultrasonic isolation. The yoke material must also be compatible with the coolant fluids.

Electronic Design

A block diagram of the electronic circuitry is included as Figure 3. The detector signals are amplified by a wide-band preamplifier with a 40-db gain. The preamp uses two cascaded CA 3001 IC video amplifiers and has a bandwidth of 0.1 to 10 MHz. Signals below 0.1 MHz roll off at 20 db per decade, which improves the low-frequency noise and shock rejection. (Low-frequency vibration and noise are not effectively attenuated by the yoke.) For still further signal-to-noise improvement, the preamp output signal is amplified to 20 db by an LC-tuned band-pass amplifier. This circuit has about a 50-kHz bandwidth and is tunable from 250 to 450 kHz. This amplifier is particularly effective in reducing electrical interference when tuned near the PZT detector resonant frequency.

Figure 3. ELECTRONICS COMPONENTS OF THE GRINDER SETTING STATION.

For level detection, the high-frequency AC signals are converted to positive pulses in a diode demodulator, and these signals are then integrated in an operational amplifier integrator with the time constant adjusted to about two revolutions of the grinding wheel at normal operating speeds. This integration reduces the effects of shock, because more than one successive contact between the grinding wheel and tool ball is required to actuate the level detector at light contact pressure. The level detector is adjustable so that field calibration for actual field conditions can provide the lightest possible contact between the ball and grinding wheel in order to minimize nicks and ball wear.

The level meter (on the output of the integrator) provides a visual reading of the average signal and noise level. Actuation of the level detector is indicated by a light-emitting diode (LED) pilot light, which can be used to aid in manual operations, set up, and calibration. A -6 to +6 V DC signal is provided for interfacing with the numerical control unit for automatic operation.

The preamp is contained in a 2 by 2 1/2 by 5-inch minibox with attached detector cable. The rest of the electronics and power supplies are housed in a small, portable instrument cabinet. An AC line filter is used to minimize line noise and interference from the grinder motor and associated equipment.

TEST RESULTS

Laboratory Tests

A prototype grinder setting station was fabricated and laboratory tests conducted using a small, vitreous-bonded grinding wheel and a jeweler's lathe grinder on a stable granite surface plate. The ball-post assembly was mounted on a small slide positioned by a differential-screw micrometer with $5\text{-}\mu\text{in}$ ($0.127\text{-}\mu\text{m}$) resolution. After adjusting the electronics (level and frequency) for optimum performance, ten micrometer readings were taken at the same spot on the ball to determine repeatability. Visual observations of the LED and level meter were used to determine contact during these tests. The ball was then rotated in 30° increments and ten readings taken after each increment, through 360° rotation. A statistical evaluation of these data gave an overall repeatability of $\pm 25.7\text{ }\mu\text{in}$ ($\pm 0.653\text{ }\mu\text{m}$), a peak-to-peak average deviation of $24\text{ }\mu\text{in}$ ($0.61\text{ }\mu\text{m}$) due to rotation of the ball, and an overall precision of $\pm 38\text{ }\mu\text{in}$ ($\pm 0.97\text{ }\mu\text{m}$) at 95% confidence.

To check effects of the contact angle and direction (between the grinding wheel and the tool ball), the grinding wheel was tilted vertically in 30° increments through 180° . Then, with the grinding wheel normal, the ball-support post assembly was rotated horizontally to 90° and 120° to determine if detector orientation affected repeatability. These changes, of course, did affect the micrometer dial average reading, but no significant changes in repeatability were found, indicating that the system is not sensitive to direction and, hence, can be used to set both axes of a machine.

Field Tests

Additional tests, to determine the effects of shop conditions and grinding wheel coolants, were conducted manually on production grinders. Repeatability of the settings was verified by an LVDT readout of the position of the grinder shaft. The repeatability observed during these tests was about the same as for laboratory conditions [$\pm 40\text{ }\mu\text{in}$ ($\pm 1.0\text{ }\mu\text{m}$)]. The signal amplitude was, however, greatly reduced when the grinding wheel was wet with coolant, which required a reduction in the level setting for normal operation. This reduction is probably due to a cushioning effect from the coolant fluids. Effects of external shock and vibration were appraised by dropping a one-inch tool ball from waist height to the floor near the machine and by tapping on the adjacent machine with screwdrivers and wrenches while observing the LED indicator. No false triggers were observed.

Numerical-Control Machine Tests

The prototype was then installed on a production NC grinder and a program written to use the setting station for automatic wheel setting. At first, electrical interference in this area was too great to allow for an effective use of the station. Additional shielding and line filtering were added to reduce susceptibility to this interference. Two interfering sources (MG set brushes and an NC power supply) were identified and corrective maintenance performed. Other interfering sources (eg, crane, arc furnaces, and drill motors) were identified and their effects reduced by changing the cable shielding and electrical grounding arrangement.

The NC machine system repeatability was then observed, using the machine axis readouts and the automatic tool-set program. The repeatability for 12 readings taken at one-half-hour

intervals over a seven-hour period was $\pm 125 \mu\text{in}$ ($\pm 3.2 \mu\text{m}$) on one axis and $\pm 250 \mu\text{in}$ ($\pm 6.35 \mu\text{m}$) on the other axis. These figures include not only the setting-station variance, but all the machine errors (ie, spindle growth, slide, stick slip, NC dropped counts, and backlash, but not wheel wear). The difference between the two axes can only be attributed to machine errors, as the setter station is not sensitive to direction. These errors were attributed primarily to spindle growth which can be compensated for by a frequent setup. After the spindle had been running for several hours at constant speed, a precision of $\pm 35 \mu\text{in}$ ($\pm 0.85 \mu\text{m}$) was obtained for a short term (1 hr) on both axes. Three small parts have been fabricated, with a wheel-position accuracy of $\pm 75 \mu\text{in}$ ($\pm 1.9 \mu\text{m}$) implied from the finished part dimensions. This value compares favorably with the $\pm 500 \mu\text{in}$ ($\pm 12.7 \mu\text{m}$) expected from standard industrial practice in grinding wheel settings.⁽²⁾

SPECIFICATIONS

Salient specifications of the grinder setting station are as follows:

Sensing Method

Ultrasonic-acoustic contact between grinding wheel and tool ball.

Detector

PZT-5 ceramic, differential screw-on cartridge.

Repeatability

Repeatable within $\pm 40 \mu\text{in}$ ($\pm 1.0 \mu\text{m}$) under laboratory conditions ($\pm 2^\circ\text{F}$ ambient temperature fluctuation and stable AC line).

Outputs

Meter - Voltage of 0 to 5 on the meter indicates an average signal level.

Light - LED indicates signal above the level detector setting.

NC Interface - DC voltage of -6 when signal is below the level detector setting and $+6$ for signal above the level setting.

Controls

Adjustment of frequency of band-pass amplifier by internal capacitor.

Level Detector - Front-panel, 10-turn potentiometer, approximately 5 V full scale.

Time Constant

Approximately 40 millisec (2 revolutions at 3000 rpm).

Power

Power setting from 105 to 125 V AC, 60 Hz, 20 W. (This power level should be reasonably clean as excessive line noise may interfere with the automatic operation.)

Physical

The system consists of three parts interconnected by cables.

Detector Post Assembly - Post is 3 1/2 inches high by 2 inches in diameter at the base. Designed to clear a 3-inch-radius grinding wheel in contact with a 1-inch tool ball.

Preamplifier - Preamp is mounted in a 2 1/4 by 2 1/2 by 5-inch minibox. A short detector to the preamp cable should be used.

Meter Cabinet - This unit contains all power supplies, controls, indicators, and outputs, and is 8 inches high by 6 inches wide by 8 1/4 inches deep.

APPLICATION PRECAUTIONS

In order to profitably apply this development to improve grinder accuracy, certain precautions are in order:

1. A good, stable machine, operated in a temperature-controlled environment, must be used if full advantage is to be taken of the instrument capabilities.
2. Care must be exercised in designing the ball-post support mount to avoid mounting types which may show flexures with respect to the machine axes.
3. A stable, clean AC power source is advisable.
4. The ball-post assembly is designed for wheels up to three inches in radius, but the assembly can be easily redesigned for larger wheels or made smaller for smaller machines with little expected effect upon the accuracy.
5. Overall precision will be limited primarily by the grinding machine in most installations.

REFERENCES

- (1) "Numerical Controlled Grinding Machines", *Steel Magazine*, 161 (23); December 4, 1967.
- (2) "Analysis of Errors in Grinding Operations", *ASTME Creative Manufacturing Seminars*, 1968, Tech Paper MR68 - 758; September 1968.

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